X-640-65-194

QUASI-BIENNIAL CYCLES IN COSMIC-RAY INTENSITY

by

Kaichi Maeda

May 1965

[redacted]

NASA—Goddard Space Flight Center
Greenbelt, Maryland

QUASI-BIENNIAL CYCLES IN COSMIC-RAY INTENSITY

Since its discovery in the tropical stratospheric wind system by Veryard and Ebdon (1961), many features of the biennial variation or the so-called 26-month oscillation of the earth's atmosphere have been fairly revealed in the past few years, except the theories to explain its origin and mechanisms (Reed 1962, 1963, 1964 and 1965; Reed and Rogers 1962; Staley 1963; Belmont and Dartt 1964; Dartt and Belmont 1964; Newell 1964; Kriester 1964; Sparrow and Unthank 1964; Westcott 1964).

The intent of this short note is to point out the usefulness of certain cosmic-ray data for investigating this phenomenon, and to show one preliminary result obtained by power spectrum analysis of cosmic-ray data.

Cosmic-ray intensities observed at the earth's surface are continuously modulated not only by astrophysical variations in outer space (particularly magnetic field variations) but also by atmospheric variations. Due to the decay processes of unstable components such as pions and muons produced by incoming primary cosmic-ray particles in the upper atmosphere, cosmic-ray intensities at the ground change with variations of barometric pressure and of the atmospheric temperatures (Jánnosy 1950; Dauvillier 1954; Heisenberg 1953; Dorman 1957). Therefore, the cosmic-ray muon data — which are more commonly called cosmic-ray meson data or the hard component intensities — measured at the ground and corrected for barometric effect are very good indicators of continuous atmospheric temperature variations, provided that information about the geomagnetic variations is available. For this reason we can expect that variations occurring in the upper atmosphere should also be found in the pressure-corrected cosmic-ray muon data.

The variation of cosmic-ray intensity at the ground due to atmospheric temperature variation is an accumulated affect of the differential contribution from each layer in the atmosphere, which are not only functions of the altitude of each layer in the atmosphere but also of the cut-off energy of the observed cosmic rays. The latter depends on the geomagnetic and geographic location of the observing station and on the parameters of the measuring instrument, such as shield thickness and type of cosmic-ray detector. These relations are well known both experimentally and theoretically, and can be expressed by the simple formula:

$$\frac{\delta I}{I_0} = \int_0^{x_0} \gamma(E_0, x)\, \delta T(x)\, dx \ ,$$

$$\cong \sum_{i=0}^{n} \gamma(E_0, x_i)\, \delta T(x_i)\, \Delta x_i$$

where I_0, δI are the mean and the deviation of cosmic-ray intensity at the atmospheric depth x_0 due to the temperature variation, δT at the depth x in dx.

$\gamma(E_0, x)$ is called the partial temperature coefficient, which indicates the relative variation of cosmic-ray muon intensity with cut-off energy E_0 at the depth x_0, due to a 1°C increase in the layer δx at x. Details of these coefficients as the function of E_0 and x, as well as comparisons with the experimental data have been discussed by many workers (Maeda and Wada, 1954; Trefall 1955 a,b; Wada and Kudo, 1956; Dorman, 1957; French and Chasson, 1959; Mathews, 1959; Wada 1961; Carmichael et al., 1963, 1965). It should be noted that the atmospheric temperature effect on cosmic-ray intensity consists essentially of two parts: one is positive and due to the change in the production rate of cosmic-ray muons with temperature variations in the upper atmosphere, and the other is negative, corresponding to the change of decay-rate of muons in the atmosphere. Therefore, the temperature coefficient is usually negative for usual cosmic-ray data with cut-off energies of less than the order of 0.5 Gev. On the other hand, the positive effect dominates at high energies, particularly above the production level of cosmic-ray mesons, i.e., above the 200 mb level, because the decay-rates of muons produced in the atmosphere with energies higher than several Gev are practically negligible.

It is known that the phase of the 26-month oscillation in the upper atmosphere differs with height, shifting from higher altitudes downward with a rate roughly of the order of 1 km/month. This is shown in the upper curves in Figure 1 in which the variations of the stratospheric temperature differences between 3°S and 28°N are plotted from data obtained during the period from 1951 to 1961 at four different levels above 100 mb (Reed, 1965).

Since the phase of the 26-month oscillation and the effect of temperature variation on cosmic-ray intensity differ with height, this type of information is best for observing the corresponding variations in cosmic-ray intensities at the ground.

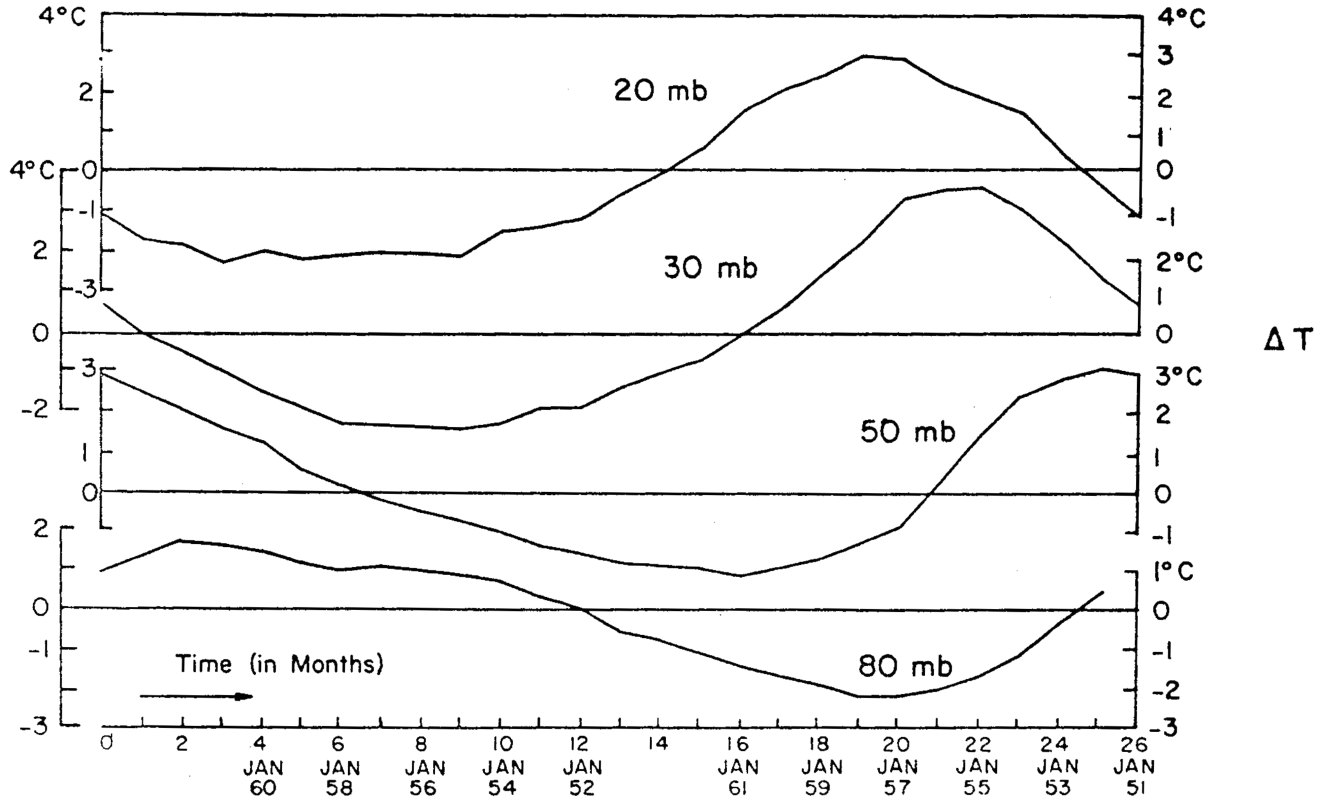
By using the above mentioned formula, we can see the amplitude and phase of 26-month cosmic-ray variation for the corresponding periods of years. These are shown in the lower portion of Figure 1, for these different cut-off energies, i.e., $E_0 = 0.3$ Gev (heavy solid line), 10 Gev (dashed line) and 40 Gev (light solid line), respectively, where $\gamma(E_0, x)$'s are taken from previous calculations (Maeda, 1960). Since the relations between variations of the atmospheric temperature $\delta T(x)$ and those of the cosmic-ray intensity δI are linear as shown by the previous formula, the three curves shown in Figure 1 correspond to the 26-month variations in the difference of cosmic-ray intensities between 3°S and 28°N. It is known that 26-month variations of stratospheric temperature around 28°N are very small as compared with those near the equator (Reed 1965). Therefore, these variations can be regarded as the 26-month cycles of cosmic-ray intensity near the geographic equator, for the period from 1951 to 1961.

As can be seen from these curves, the phase relation between the 26-month oscillation in upper atmospheric temperature and that of cosmic-ray intensity at the ground is not simple but rather reversed at low energies ($E_0 < 0.5$ Gev) and at high energies ($E_0 >> 1$ Gev). This results from the different temperature effects at low energies (negative) and at high energies (positive). The former corresponds to the usual hard component data such as those observed by an ion-chamber or by the so-called cubical meson telescope, while the latter corresponds to underground cosmic-ray intensities. It should be noted that although the positive temperature effect increases with increasing cut-off energy, there is an upper limit (Maeda, 1960) and that because of its energy spectrum, the cosmic-ray intensity decreases rapidly with increasing cut-off energy.*

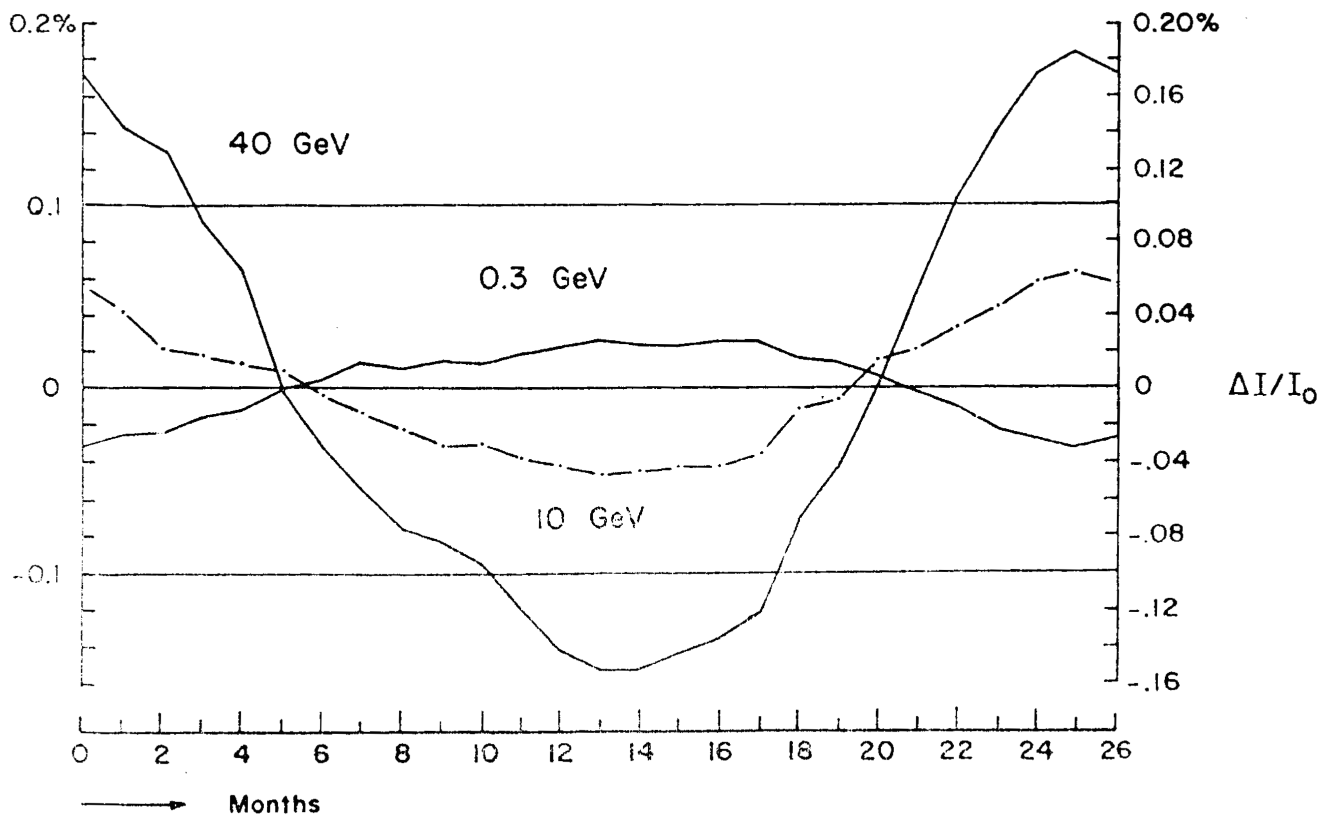
At any rate, if continuous measurements of cosmic-ray intensity had been made at the geographic equator for more than one decade, the 26-month variation with amplitude of the order of 0.03% or the maximum deviation of the order of 0.1% can be detected even by ion-chamber data. If the underground cosmic-ray measurements had been made continuously for more than several years near the geographic equator, the 26-month variation with amplitude of more than 0.2% (which is the order of magnitude observed in the diurnal variation of cosmic-ray intensity) can also be found in these data with anti-phase to those of low energies.

Since, at present, no cosmic-ray data corresponding to the curves shown in Figure 1 are available, detection of the biennial of 26-month variations in cosmic-ray intensities by means of a simple statistical method is not feasible at present. However, the so-called Type C ion-chamber, which is shielded with a 12 cm Pb - equivalent absorber, has been operated at Huancayo, Peru (12°S geographic, 3350 m above sea level) since June, 1936. Therefore, the power spectrum analysis has been made by using the monthly average data from this

*For example, relative intensities with cutoff energies $E_0 = 0.3$, 10 and 40 Gev are roughly 1:0.1:0.005, respectively.



20 mb
30 mb
50 mb
80 mb
ΔT
Time (in Months)
4°C
2°C
3°C
1°C
JAN 60
JAN 58
JAN 56
JAN 54
JAN 52
JAN 61
JAN 59
JAN 57
JAN 55
JAN 53
JAN 51



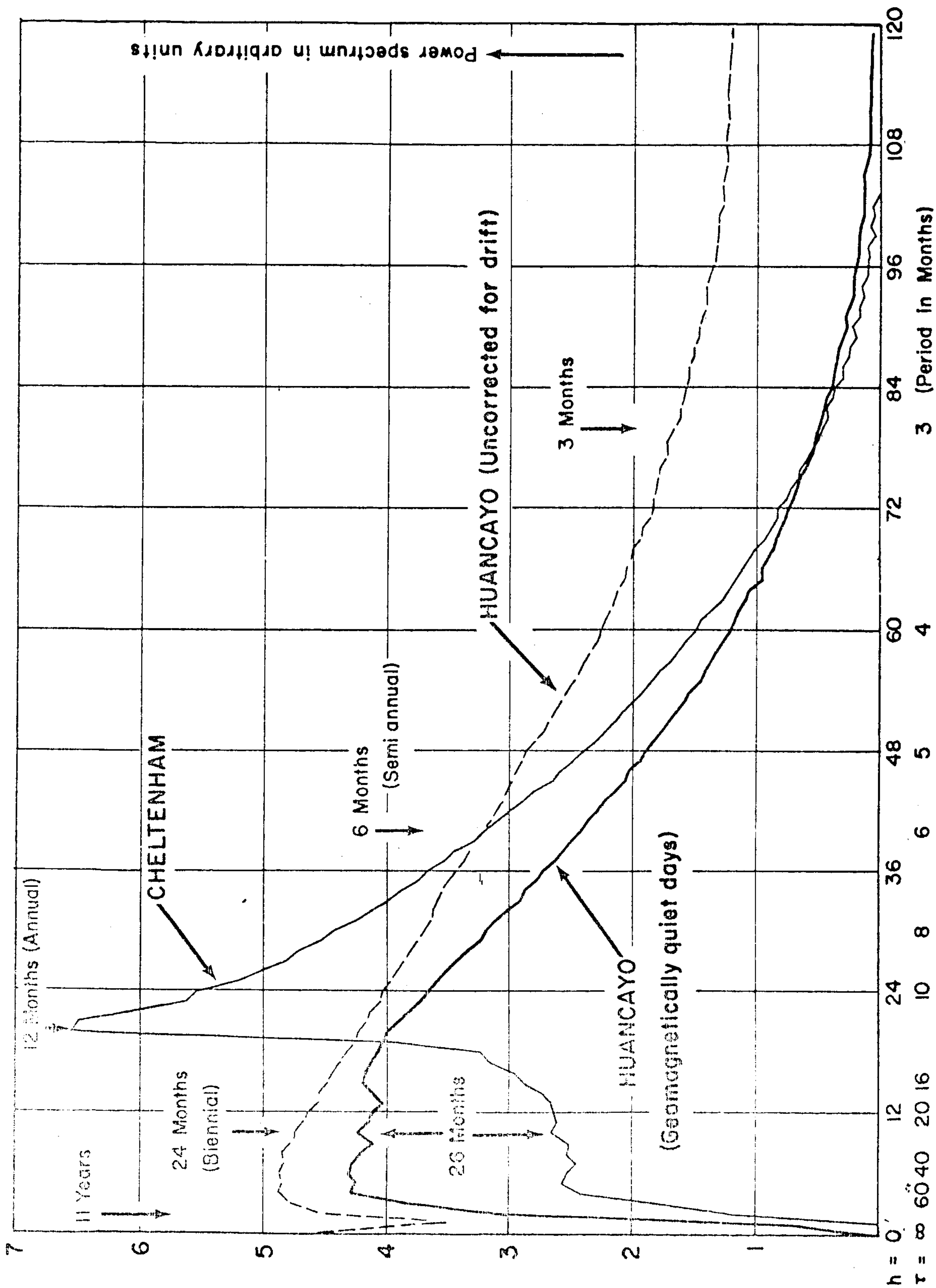
40 GeV
0.3 GeV
10 GeV
ΔI/I₀
0.2%
0.20%
Months

station for the 23-year period from 1937 to 1959. Since the identical ion-chamber has been operated at Cheltenham, Maryland (39°N, near sea level), a similar analysis has also been applied to these data for the same period. These results are shown in Figure 2, where unnormalized power spectra are plotted against the frequency h. The periods, (τ, in month) are also marked on the horizontal scale under the corresponding values of h. The computer program used in the present calculation (IBM 7094) is the same as the one applied to spectral analysis of traveling pressure waves in the atmosphere (Maeda and Young, 1964), which is based on the formula used by oceanographers (Pierson and Marks, 1952). The dashed line in Figure 2 represents the monthly mean value from Huancayo, which includes not only geomagnetically disturbed data but also the effect of drift on the recording systems. The heavy solid line is obtained by choosing "five quiet days" in each month and the data are then corrected for the drift using the formula given by Forbush (1958).

The thin solid line is obtained from the monthly average data from Cheltenham,* which included geomagnetic disturbed days. It is obvious from this figure that the well-known annual variation of cosmic-ray intensity, which strictly speaking should be called the seasonal variation because of its "anti-phase" between the two hemispheres, does not exist in the tropical region, however, rather broad bands with periods from 16 months to 60 months exist. Also, it is interesting to note that there are small peaks at 16, 24, and 40 month periods in the geomagnetically quiet data of Huancayo and similar peaks in the 24 and 48 month periods in Cheltenham data, although further accumulations of data are necessary to establish the significance of these peaks. According to a very recent investigation (Reed, 1965), the amplitude of the 26 month variation in the stratospheric temperature field is largest (of the order of 2°C) at the geographic equator above the 100 mb level, and decreases with latitude but increases again slightly beyond 20 degrees of latitude, indicating a minimum around 17 degrees in each hemisphere. It is also indicated that the phase of 26-month oscillation is reversed between these two regions, i.e., tropics and subtropics.

With reference to the atmospheric 26-month oscillations, Huancayo is located rather near the region of minimum temperature variation, but within the region of tropic oscillation (not in the subtropic). In this respect, cosmic-ray data from Lae, New Guinea (7°S geographic, near sea level) and from Makerere in Kampala, East Africa (0.33°N geographic, near sea level) are more meaningful in the present analyses. However, the data from Lae are not corrected for barometric variations and those from Makerere are limited only to the IGY period (July, 1957 - December, 1959). Therefore, from these promising stations data are left for future analysis.

*The ion-chamber was moved from Cheltenham, Maryland to Fredericksburg, Virginia in October, 1956. The difference between these two locations, which is only of the order of 100 km, is not significant in the present analysis.



Power spectrum in arbitrary units
HUANCAYO (Uncorrected for drift)
3 Months
6 Months
(Semi annual)
CHELTENHAM
12 Months (Annual)
24 Months
(Biennial)
26 Months
11 Years
HUANCAYO
(Geomagnetically quiet days)
7
6
5
4
3
2
1
h = 0 12 24 36 48 60 72 84 96 108 120
τ = ∞ 60 40 20 16 10 8 6 5 4 3 (Period In Months)

As indicated by recent aerological observations, the quasi-biennial variations are persistent even at high latitudes, especially in the southern hemisphere, including the Antarctic (Funk and Garnham, 1962; Landsberg, 1962; Landsberg et. al. 1963; Angell and Korshover, 1964; Sparrow and Unthank, 1964; Reed, 1965). Since high energy cosmic-ray data, particularly those measured underground, should be available several places in the world, quasi-biennial cycles in cosmic-ray phenomena seem to be a worthwhile subject for further investigation.

Finally, it should be mentioned that the sources of cosmic-ray variations are terrestrial as well as extra-terrestrial; therefore we can compare these effects directly (e.g., Figure 2). Thus investigations of world-wide cosmic-ray data might provide another approach in understanding the origins of these mysterious quasi-biennial oscillations in the earth's atmosphere which have been discussed recently in several different fields (Shapiro and Ward, 1962; Stacey and Westcott, 1962; Hope, 1963; Westcott, 1964; Newell, 1964 a.b.; Lindzen, 1964; Reed, 1965). The more detailed analyses on this subject will be reported elsewhere (Maeda and Suda, 1965).

ACKNOWLEDGMENT

The cosmic-ray data used in the present analysis are obtained through the courtesy of Dr. S. E. Forbush of the Carnegie Institution of Washington, D.C., to whom I am very grateful. I wish also to express my appreciation to Prof. R. T. Reed at the University of Washington, who made possible the present investigation.

REFERENCES

Angell, J. K., and J. Korshover, Quasi-biennial variations in temperature, total ozone, and tropopause height, J. Atmos. Sci., 479-492, 1964.

Belmont, A. D., and D. G. Dartt, Double quasi-biennial cycles in observed winds in the tropical stratosphere, J. Atmos. Sci., 21, 354-360, 1964.

Blackman, R. B., and J. W. Tukey, The measurement of power spectra, Dover Publications, Inc., N. Y., 1958.

Carmichael, H., M. Bercovitch and J. F. Steljes, A comparison of several methods of correcting cosmic-ray muon intensity for atmospheric temperature variations, Proceedings of International Conference on Cosmic Rays, Dec. 2 - 14, 1963, Jaipur, India.

Carmichael, H., M. Bercovitch and J. F. Steljes, Introduction of meteorological corrections into meson monitor data (Preprint), 1965.

Dauvillier, A., Les Rayons Cosmiques, Dunod, Paris, 1954.

Dartt, D. B., and A. D. Belmont, Periodic features of the 50-milliband zonal winds in the tropics, J. Geophys. Res., 69, 2887-2893, 1964.

Dorman, L. I., Cosmic ray variations, State Publishing House, Moscow, 1957, (English translation, Air Force Office of Scientific Research).

Forbush, S. E., Cosmic-ray intensity variations during two solar cycles, J. Geophys. Res., 63, 651-669, 1958.

French, W. R., and R. L. Chasson, Atmospheric effects on the hard component of cosmic radiation near sea level, J. Atmos. Terr. Phys. 14, 1-18, 1959.

Funk, J. F., and J. L. Garnham, Australian ozone observations and a suggested 24-month cycle, Tellus, 14, 378-382, 1962.

Heisenberg, W., Kosmische Strahlung, Springer-Verlag, Berlin, 1953.

Hope, E. R., Geomagnetic analog of 26 month meteorological sunspot cycle, J. Atmos. Sci., 20, 342, 343, 1963.

Jánossy, L., Cosmic Rays, Oxford-Clarendon Press, 1950.

Kriester, Barbara, Die annähernd zweijährige schwingung des zonalen windes in der tropischers stratosphäre, Meteorol. Abhand., (Berlin), 22, 1-38, 1964.

Landsberg, H. E., Biennial pulses in the atmosphere, Beitr. z. Phys. Atmos., 35, 184-194, 1962.

Landsberg, H. E., J. M. Mitchell, Jr., H. L. Crutcher and F. T. Quinlan, Surface signs of the biennial atmospheric pulse, Monthly Weather Rev., 91, 549-556, 1963.

Lindzen, R. S., Radiative and photochemical processes in strato- and mesopheric dynamics, Ph.D., Thesis, Harvard University, 1964.

Maeda, K., Remarks on annual and diurnal variation of cosmic-ray intensity (letter), J. Geomag. Geoelect., 5, 105-108, 1953.

Maeda, K., Directional dependence of atmospheric temperature effects on cosmic-ray muons at sea-level, J. Atmos. Terr. Phys., 19, 184-245, 1960.

Maeda, K., and T. Suda, The annual and diurnal variations of cosmic-ray intensity and temperature effect, J. Geomag. Geoelect., 2, 18-21, 1950.

Maeda, K., and T. Suda, La Variation Quasi Biennale des Rayons Cosmiques, Papers in Met. & Geophys., Tokyo, 1965 (in press).

Maeda, K., and M. Wada, Atmospheric temperature effect upon the cosmic-ray intensity at sea level., J. Sci., Res. Inst. (Tokyo), 48, 71-79, 1954.

Maeda, K., and J. M. Young, Propagation of pressure waves produced by auroras, Proceedings for the Second Benedum Earth Symposium, Pittsburgh, November, 1964. (in press)

Mathews, P. M., Atmospheric effects on cosmic-ray intensity at sea-level, Can. J. Phys., 37, 85-101, 1959.

Newell, R. E., A note on the 26-month oscillation, J. Atmos. Sci., 21, 320-321, 1964.

Newell, R. E., 26-month oscillation in atmospheric properties and the apparent solar diameter, Nature 204, 278, 1964.

Pierson, W. J., and W. Marks, The power spectrum analysis of ocean-wave records, Trans. Amer. Geophys. Union, 33, 834-844, 1952.

Reed, R. J., Some features of the annual temperature regime in the tropical stratosphere, Monthly Weather Rev., 90, 211-215, 1962.

Reed, R. J., On the cause of the 26-months periodicity in the Equatorial stratospheric winds, Meteorol. Abhand., Berlin, 36, 245-257, 1963.

Reed, R. J., A tentative model of the 26-month oscillation in tropical latitudes, Quart. J. Roy. Met. Soc., 90, 441-466, 1964.

Reed, R. J., The present status of the 26-month oscillation, Paper delivered at 45th annual meeting of the Am. Met. Soc., New York, January, 1965.

Reed, R. J., and D. G. Rogers, The circulation of the tropical stratosphere in the years, 1954 - 1960, J. Atmos. Sci., 19, 127-135, 1962.

Shapiro, R., and F. Ward, A neglected cycle in sunspot numbers, J. Atmos. Sci., 19, 506-508, 1962.

Sparrow, J. G., and E. L. Unthank, Biennial stratospheric oscillations in the southern hemisphere, J. Atmos. Sci., 21, 292-596, 1964.

Stacey, F. D., and P. Westcott, Possibility of a 26 or 27 month periodicity in the equatorial geomagnetic field and its correlation with stratospheric winds, Nature, 196, 730-732, 1962.

Staley, D. O., A partial theory of the 26-month oscillation of the zonal wind in the equatorial stratosphere, J. Atmos. Sci., 20, 506-515, 1963.

Trefall, H., On the positive temperature effect in cosmic radiation, Proc. Phys. Soc., 68A, 625-631, 1955a.

Trefall, H., On the positive temperature effect in the cosmic radiation and the Mu-e decay, Proc. Phys. Soc., 68A, 893-904, 1955b.

Veryard, R. G., and R. A. Ebdon, Fluctuations in tropical Stratospheric winds, Meteorol. Mag., 90, 125-143, 1961.

Veryard, R. G., and R. A. Ebdon, The 26-month tropical stratospheric wind oscillation and possible causes, Proceedings of International Symposium on Strato-Mesospheric Circulation, Aug., 1962, Berlin, Meteorol. Abhand., 36, 225-244, 1963.

Wada, M., Atmospheric effects on the intensity of Cosmic-ray mesons, (II), the temperature effect., Sci. Paper, Inst. Phys. Chem. Res., (Tokyo), 55, 7-23, 1961.

Wada, M., and S. Kudo, A statistical investigation for the atmospheric temperature effect on Cosmic-ray intensity, J. Sci. Res. Inst., (Tokyo), 50, 1-9, 1956.

Westcott, P., The 25-26 month periodic tendency in sunspots, J. Atmos. Sci., 21, 572-573, 1964.